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THE SMALL SCIENTIFIC SATELLITE (S^3) PROGRAM AND ITS FIRST PAYLOAD

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GODDARD SPACE FLIGHT CENTER
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Greenbelt, Maryland

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ABSTRACT

The Small Scientific Satellite (S^3) program provides a scientific "bench" which can be used by experimenters for a wide variety of investigations in the magnetosphere and near interplanetary space, employing the Scout launch vehicle. In the conduct of these scientific missions, the S^3 program affords the experimenter control over parameters affecting the investigation, e.g. orbit, attitude control, and orientation. In addition, complete in-flight control of the data format is available through the use of an on-board set of stored program instructions which govern the collection of data and which are reprogrammable via ground command. Many of the spacecraft subsystems are modular and are used according to the experimenter's needs. This paper will describe the concept of the S^3 program, the characteristics of the various subsystems, research capabilities of the program, and the first payload as a space nuclear instrumentation system.

THE SMALL SCIENTIFIC SATELLITE (S^3) PROGRAM AND ITS FIRST PAYLOAD

INTRODUCTION

It is now some ten and one-half years since Dr. J. A. Van Allen and his colleagues at the University of Iowa[1] discovered the earth's trapped radiation with instrumentation aboard the U. S. satellites Explorers 1 and 3, and so initiated an active and very fruitful decade of space research.

In this decade much has been learned of the earth's environment, mainly through the use of small unmanned research satellites.[2] Interplanetary conditions which shape and perturb the earth's magnetic field environment have been studied. Details of the resulting geomagnetic field configuration—the magnetosphere, with its bow shock, transition region, and magnetic field termination, the magnetopause—have been investigated. The extended geomagnetic tail has been discovered, and related day-night asymmetries in the geomagnetic field have been probed.

The major particle populations and the structure of the trapping regions have been mapped out. Some of the dynamics of the interplay between the magnetosphere and the particle populations have been determined. Theoretical and experimental studies of the basic plasma properties which play a key role in determining the dynamic characteristics of the magnetosphere and its particle populations have yielded insights to particle transport, acceleration and loss mechanisms. In addition to studies of the near-earth environment, investigations of solar and galactic cosmic rays and of interplanetary fields and plasmas have been made, as well as direct observations of solar emissions in various wavelength regions.

This vast new body of knowledge, rather than answering all our questions about the earth's environment, has actually presented a far more complex picture than was ever envisioned; and raises a host of new problems—problems which pertain not only to the earth's environment and its interaction with interplanetary space, but also to such diverse yet related subjects as the solar system interface with the galaxy; anomalously high diffusion rates in plasmas; mechanisms of collisonless shock formation in plasmas and in interplanetary and interstellar regions; and energy transformation mechanisms in stars and pulsars.

These new and more physics-oriented problems which have recently arisen suggest that the exploratory phase of near-earth space research is near its end.

While some explorations remain to be done, e.g., of high altitude regions over the polar caps, the emphasis now is on specific problem-oriented investigations.

Such studies in general require sophisticated instrumentation and demand the very careful measurement of several parameters during the course of the phenomenon being investigated. This, in turn, requires that a set of very closely integrated sensors—a set of sensors comprising a single overall experiment—be flown by a group (or groups) of researchers for a specific investigation of interest. The Small Scientific Satellite, S^3, provides an experiment "bench" capable of a variety of such missions utilizing the economical Scout launch vehicle.

Examples of the types of studies that can be carried by this system are: solar particle studies; x-ray and gamma-ray studies; bow-shock studies; particle and field measurements in the magnetosphere and in the geomagnetic tail; auroral zone studies; and atmospheric studies.

Experiment proposals using the entire satellite are encouraged. In this way, a group of researchers can maintain tight control over all the design parameters in their investigation. They can choose the orbit, stabilization, orientation, and data system functions desired, and any other parameters pertinent to their investigation. In keeping with the concept of a small satellite instrumented as an overall experiment is the precept that the satellite data, housekeeping as well as experimental, will not be separated at any stage of handling and reduction. The final output to the experimenter will be an experimental tape that includes all the data from the satellite.

With such experimental tools we look forward to the next decade of space research with as much enthusiasm and excitement as have prevailed for the past ten years. It is noteworthy that the unmanned space research of the next decade not only can be accomplished at the same low cost as in past years (a cost which compares favorably with ground based physics experiments) but also can yield a similarly fascinating scientific return.

S^3 SYSTEM CHARACTERISTICS

The first steps in the attempt to design a small versatile scientific satellite system were to establish directly from the scientific community the need for such a system, and subsequently to define the requirements that the system must satisfy. Eighteen groups of satellite experimenters with experience in magnetospheric, interplanetary, solar, and atmospheric research were interviewed and asked to project their system and subsystem needs well into the future. The results of these interviews were used to establish general guidelines

Table 1
Nominal S^3 Characteristics

- 80 to 150 pound spacecraft weight
- 10 to 50 pound experiment weight
- 28 watt power budget at launch
- 13 watts for experiments (10% eclipse)
- 1 year nominal lifetime
- 20 watt power budget after 1 year in worst-case radiation belt environment
- 5 watts for experiments after 1 year (10% eclipse)
- 27 inch spherical shape approximated by polyhedral structure
- Suitable for scout launch
- Obtains flexibility by employing a modular concept for spacecraft subsystems
- Reprogrammable on-board data handling system
- High data rate capability
- Approximately 18 months lead time from acceptance of experiment proposal to launch
- Beginning of payload integration 6 months before launch

for the design of the S^3 system.[3,4,5] While the missions suggested by the contacted groups were many and varied, all expressed the need and desire to fly a tightly integrated experiment aimed at studying a particular physical phenomenon.

It is thus the intent of the S^3 program to develop a basic satellite design capable of accommodating a large variety of detector configurations suitable for many different missions. Obviously, not all experimenter requirements can be met. However, the continued direct contact with the space research community throughout the design and development phases gives us confidence that S^3 will be a useful research tool for many years to come.

General Information

Table 1 is a list of nominal S^3 characteristics.

The nominal payload weight range of 80-150 pounds is dictated by two considerations: (1) the spacecraft must be compatible with the Scout launch vehicle, and (2) high altitude missions must be accommodated. The presently available four stage Scout can place 80-90 pound payloads in elliptical orbits with apogees out to 6-7 earth radii. The projected capabilities of improved versions of the Scout are shown for comparison in Table 2. The apogee altitudes shown assume a due east launch from the Wallops Island facility and a perigee altitude of 280 kilometers.

Table 2
Projected Scount Payload Capability

Payload Weight	Apogee Altitude (Earth Radii)			
	Present 4-Stage Scout	Present 4-Stage +5th Stage	Improved 4-Stage	Improved 4-Stage +5th Stage
80 lbs	7	30	34	**
150 lbs	3	*	4.5	8.5

*Present 5-stage Scout limits payload weight to $\leq$ 100 lbs.
**Escape velocities obtainable with payload weights up to approximately 110 lbs.

Additional details concerning the system characteristics listed in Table 1 will be described in following sections. We note at this time that, with the basic S^3 system, it is possible to achieve a lead-time of only 18 months from proposal acceptance to launch, and an experiment integration time of 6 months or less. These features make the program desirable for graduate studies, since the student has the opportunity to participate on a reasonable time scale in all phases of a satellite experiment–design, construction, launch, and data analysis. In addition, graduate schools need not carry the burden of maintaining complete satellite system, subsystem, and business-management capabilities, since the S^3, which houses the experiment, will be the responsibility of NASA and its contractors.

Mechanical Design

The S^3 engineering test unit structure is pictured in Figure 1. The structure consists of lower, middle, and upper sections and weighs approximately 8 pounds. It is constructed primarily of riveted sheet aluminum to minimize weight and cost.

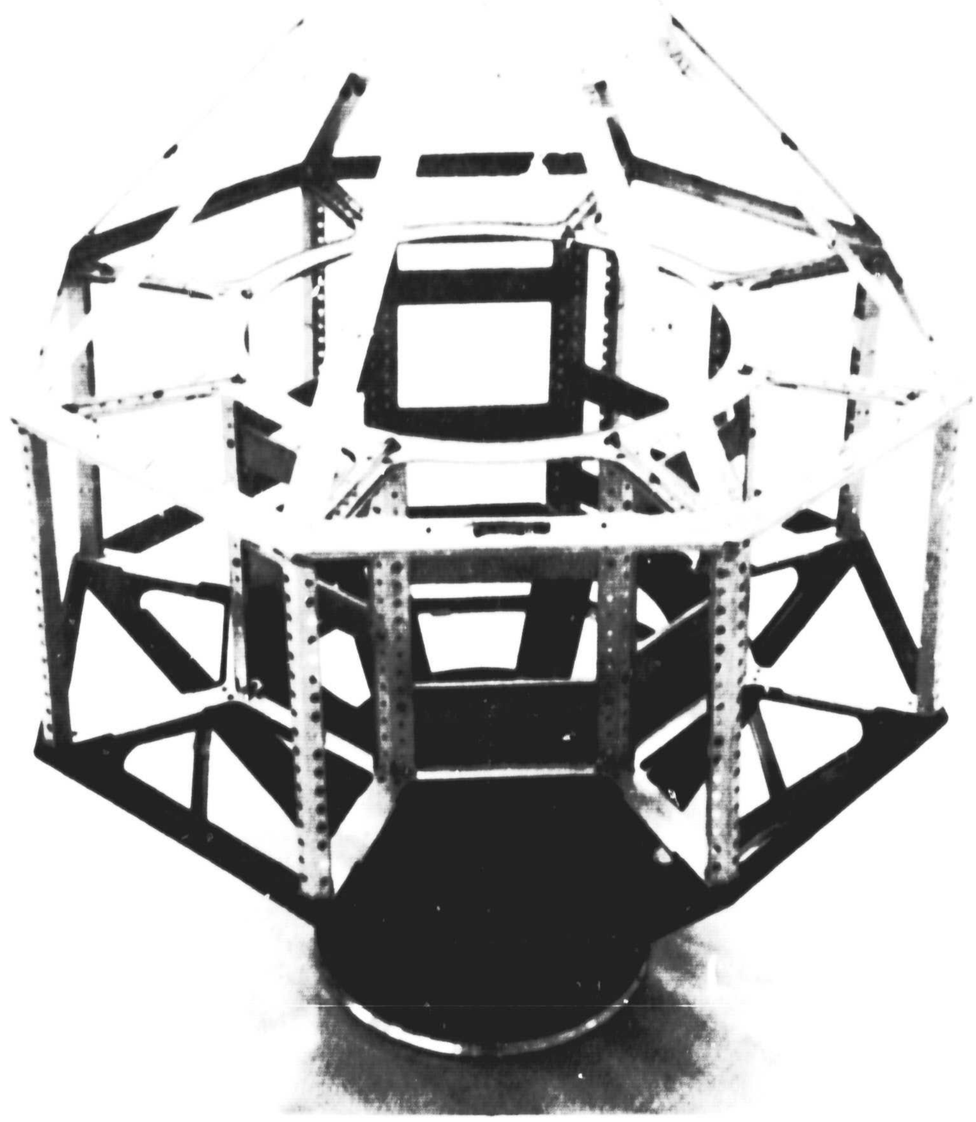

Figure 1–S^3 Structure Showing Lower (Support), Middle and Upper Sections

The lower section carries the primary load and is composed of the center tube, an interface ring, and the lower support structure. The center tube is a rolled and riveted sheet aluminum tube 9 inches in diameter and 14 inches long. It houses the battery pack and tape recorder. The tube is riveted to the machined aluminum interface ring which, in turn, is bolted to the Scout "E" section adapter. Trapezoidal-shaped solar cell panels are attached to each facet as indicated in the diagrammatic sketch of Figure 2.

The mid-section houses most of the instrumentation and experiment subsystems. Detectors and electronics are packaged in trapezoidal-shaped frames that are plugged in from the periphery of the mid-section. Each frame has a cross-sectional area of approximately 40 square inches, and its height can vary

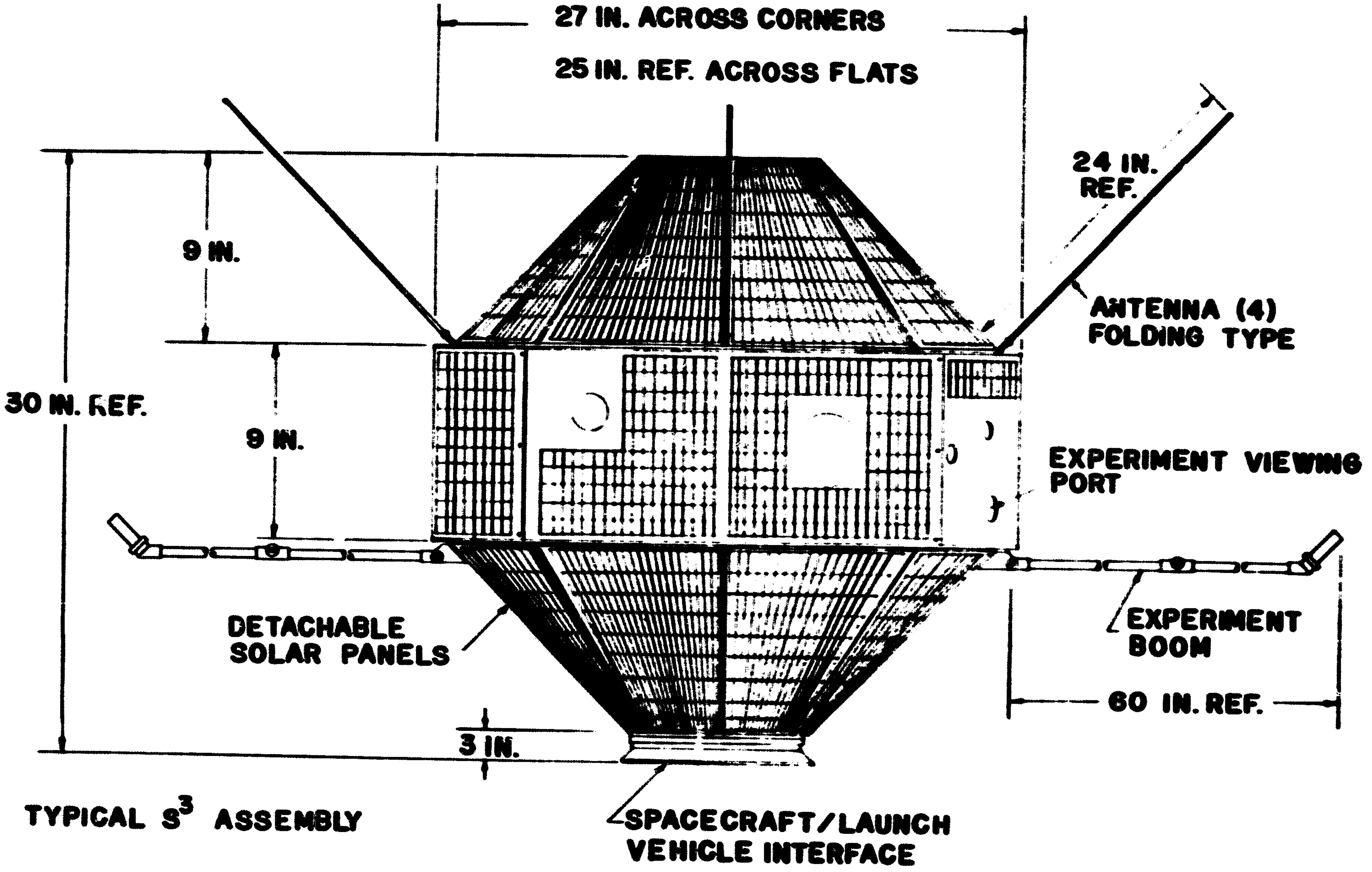

Figure 2–S^3 Diagram Showing Nominal Dimensions, Structural Features and Solar Cell Mounting

from 1/2 inch to 8 inches. Four of the eight sectors are occupied by the basic spacecraft subsystems, with the remaining four sectors available for detectors. An additional central section can be included if needed for detectors requiring large volumes. The wiring harness is affixed in the center portion of the spacecraft, and the subsystem frames can be inserted and removed without handling the harness, thus enhancing reliability. Rectangular solar cell panels are attached to all facets not interrupted by experiment apertures. Booms are available for instrumentation requiring them.

A basic weight summary for the nominal S^3 is shown in Table 3. The structural weight listed in Table 3 includes the basic structure just discussed plus mount ring, boom hinge assemblies, thermal blanket, boom release, yo-yo de-spin system, and balance weight allowance. With slight modifications to the lower structure, significantly larger experiment weights can be accommodated to take advantage of the Scout capability for low circular orbits. It is estimated that experiments in the 150-170 pound class could be handled with a total orbital weight of 280 pounds.

Table 3
S^3 Weight Summary

Basic Subsystems	
Data Handling System	7.0
Power	24.2
Telemetry	2.3
Command System	4.3
Power Control	2.5
Harness	6.6
Structure	15.5
Basic Subsystems Weight	62.4
Optional Subsystems	
Data Sync Clock	1.0
Tape Recorder	6.2
Attitude Determination	
Optical Aspect	1.2
Celestial Aspect (SCADS)	3.3
Attitude and Spin	2.9
Rate Control	
Optional Subsystems Weight	14.6

The S^3 structure is thought to combine the best features of low cost; simplicity in design and fabrication; ease of assembly; standardization of hardware; ease of mechanical and electrical integration and test; interchangeability of subsystems; vibration damping; and ease of thermal control. This structural concept is important to the overall requirement of adaptability to a variety of missions.

Electrical Design

The basic S^3 power system consists of a solar array, battery, solar array shunt regulator, battery charger, battery discharge regulator, and instrumentation converter.

The solar array supplies power for the spacecraft loads and recharges the spacecraft battery. The major part of the array power is transmitted directly to the spacecraft load; the remainder, controlled by the charge regulator, charges the battery.

The shunt regulator, by dissipating excess solar power, limits the maximum bus voltage to 28 volts plus 2 percent. The charge regulator controls the battery charge. A discharge regulator limits the minimum bus voltage to 28 volts minus 2 percent when the spacecraft loads exceed the array capability. When the available array power is adequate, the regulator remains in a standby condition, sensing the main bus voltage. Most basic spacecraft subsystems are powered directly from the main bus through the instrumentation converter. Other spacecraft subsystems, peculiar to a particular mission and detector complement, will interface with the main bus through separate converters to provide the required voltage levels, regulation, and isolation.

Great care has been taken in the electrical design of the spacecraft and all subsystems to minimize magnetic contamination and RF interference. For example, to maintain a low RF background in the critical VLF band (a frequency region of considerable interest in magnetospheric and interplanetary research), all converters operate at a minimum of 20 kHz. To satisfy experiments having high frequency requirements, converter operation in the band 20 kHz ±2% will be tried along with additional provisions such as shielding and filtering for noise suppression. To satisfy magnetic field experiment requirements, special wiring practices and component selection procedures are employed to keep the level of stray magnetic fields from any subsystem at $\leq 5\ (10)^{-6}$ gauss at a distance of 50 cm.

In following the basic S^3 philosophy of system flexibility, certain design provisions are made to allow an increase in the power system capability. With

regard to the conversion electronics, the regulators are designed to handle power increases to 60 watts. Additional solar array power can be achieved by supplementing the body-mounted array with fold-out panels or paddles.

Stabilization and Attitude and Spin Control

The initial method of stabilization is by spin stabilization in the rough range of 4 to 40 revolutions per minute. Future plans include add-on modules to provide magnetic and/or gravity gradient stabilization.

For the spin stabilization mode, subsystems have been developed to allow control of the spin axis orientation and spin rate. The first S^3 will use a magnetic attitude and spin control system (ASCS) in which control torques are generated by the magnetic moment interaction of current-carrying coils aboard the satellite with the earth's magnetic field.

In this operation, the two control functions of the ASCS, attitude and spin, are essentially independent. Both consist of "vacuum-core" coils made with hundreds of turns of fine aluminum wire epoxied in fiberglass forms. The spin rate coil is mounted in the top section of the spacecraft in a plane parallel with the spin axis. It consists of some 500 turns (1750 feet) of AWG #31 wire and weighs approximately 0.3 pound. The power to the coil is switched twice per roll period in accordance with the output of the ASCS magnetometer sensor to develop motor action; hence, a pulsating torque is developed. The spin axis attitude coil is also mounted in the top section of the spacecraft but in a plane perpendicular to the spin axis. It consists of approximately 435 turns (2700 feet) of AWG #29 wire and weighs an estimated 0.6 pound. The torque generated by this coil will be constant.

The ASCS will be activated by command; however, power will be applied to either coil as controlled by its magnetometer. During an inbound pass, as the satellite approaches perigee, the magnitude of the ambient magnetic field increases. When the magnetometer senses a predetermined field strength, power is applied to the coil. Power is removed from the coil on the outbound portion of the pass when the field strength falls below the threshold. The threshold field strength chosen is based on a unique design approach which selects system design parameters to minimize the energy-weight product. A direct "on" and "off" command control mode is also provided.

A low duty cycle is sufficient to maintain the desired orientation and spin rate. The total ASCS weighs approximately 2.9 pounds and requires 3.1 watts when operating. Other control systems such as cold gas or subliming solid thrusters are available depending on mission assignments.

Aspect Determination

Two aspect-determination systems are available, depending on the accuracy required. A system utilizing a digital solar sensor and earth detectors provides aspect accuracies to ±3/4 degree. A star mapping system termed Scanning Celestial Attitude Determination System (SCADS) is being developed which will determine the spacecraft attitude within ±0.1 degree or better.

Basically SCADS consists of a lens system, a reticle with a narrow slit, a phototube, and processing electronics. As the look cone traces an anular ring on the celestial sphere, the relative magnitude of stars crossing the slit and their crossing times, or angular separation, are measured. The system is designed to operate with stars of fourth magnitude and brighter. These measurements together with a star map provide the star identification and resultant spacecraft orientation.

On a spinning spacecraft, the celestial scan is provided naturally. On a non-spinning spacecraft, provision will be made to rotate a scanning disc with respect to the spacecraft. The system for the first mission, a spin-stabilized spacecraft, will weigh approximately 3.3 pounds and require less than 0.5 watt.

Data Processing System

The keystone of the S^3 program in the fulfillment of its scientific objectives is the data processing system (DPS). The DPS in general consists of the entire data handling process which begins with the sensor outputs on the spacecraft and ends with an experimenter's data tape and data display suitable for immediate analysis. Thus it is clear that the on-board and ground portions of the DPS must be well matched at all times.

On-Board Data Handling. An efficient and flexible on-board data handling system is required if S^3 is to service the various missions that have been proposed. This flexibility is achieved through the use of stored programs which govern in-flight data collection, through a modular design whereby only required elements need be flown, and through the use of an input/output module (IOM) to interface all sensor outputs with the data handling system.

The capability of in-flight changes in the on-board stored programs is one of the most important features of the S^3 concept, as it allows the experimenter complete control at all times of the data format being compiled from the experiment. Thus he can conduct experiments in space in much the same manner as in the laboratory. Data collection may be optimized for a specific study, and unexpected observations may be investigated in greater detail by varying the sampling rate of

any given sensor or varying the number of sensors sampled at any one time. In addition, sensors that have failed or are providing insignificant data may be removed from the sampling scheme.

Since the IOM is designed for a specific mission and contains the processing and control functions necessary for handling data unique to the mission, the experiment interface is simplified and detector systems become less complex and more economical. In addition, only the IOM requires hardware modification for each mission.

Figure 3 is a block diagram of the basics of the S^3 on-board data handling system. The main blocks of this system are:

(1) the input/output module (IOM)

(2) the central processing unit (CPU)

(3) the buffer memory

(4) the program memory

(1) IOM: The IOM is the interface between all sensors and the on-board data handling system. All data (analog, digital and/or random pulse data) enter the data handling system at this point. Within the IOM there are 64 addressable data channels which are sampled at a rate and in an order determined by the stored program instructions residing in the program memory and executed by the CPU. The type of data inputting a given addressable channel is assigned by the experimenter.

Logic is available for either serial or parallel readout of registers in the experiment package. Programmable gates, accumulators up to 20 bits in length and logarithmic compressors are available for random pulse data. Program instructions control the accumulator gates and thereby control not only the sampling rate and sequence but also the accumulation time.

In general, only one analog-to-digital (A/D) converter will be flown, normally of 10-bit accuracy. However, it is possible through the program instructions to transmit all 10 bits, the most significant 8 bits, the most significant 4 bits, the least significant 8 bits, or the least significant 4 bits.

In addition to the above 64 addressable channels, there are 128 non-addressable subcommutated channels of analog or parallel digital data which are used primarily for satellite and experiment housekeeping functions.

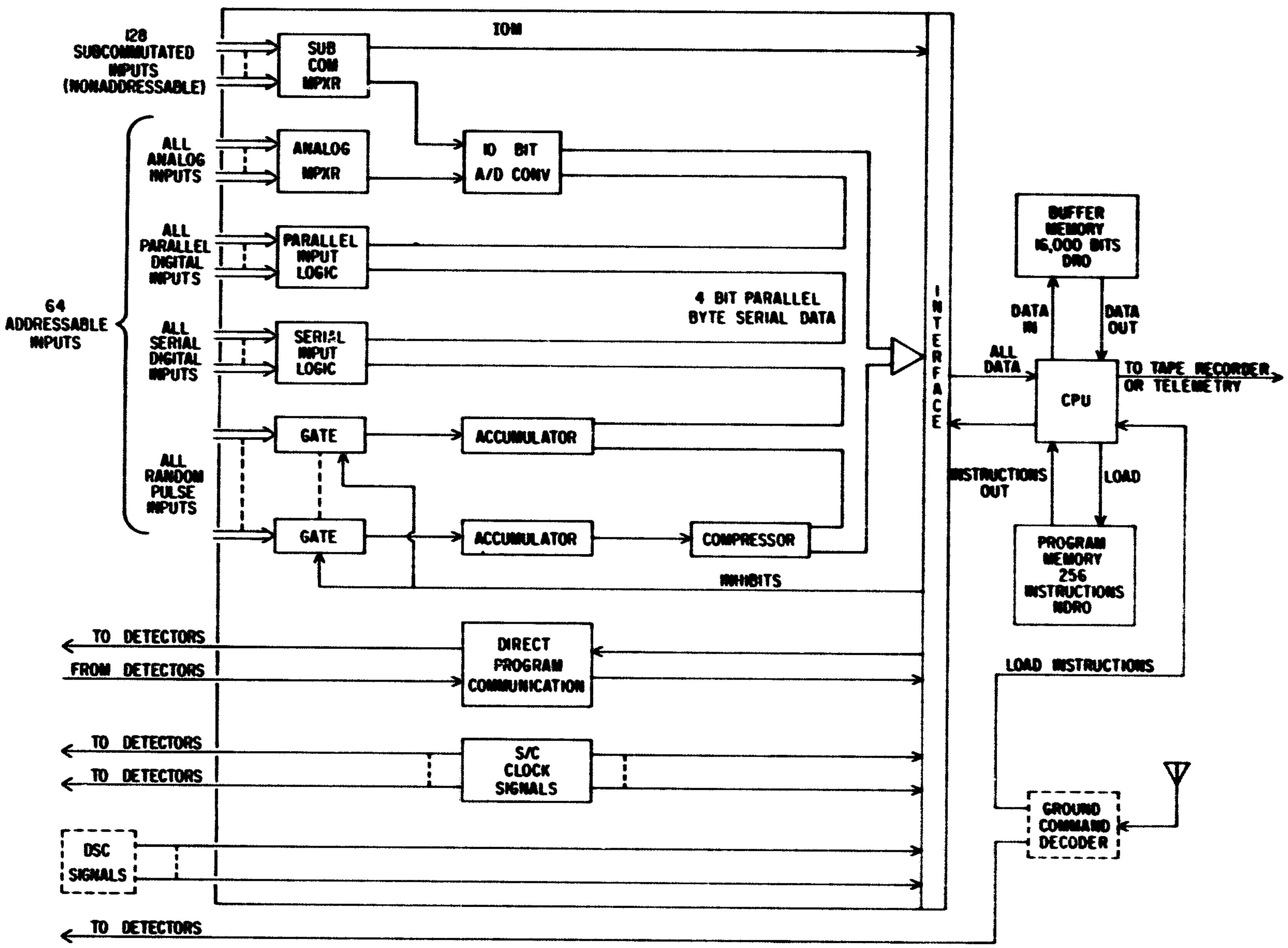

Figure 3—Block Diagram of S^3 On-Board Data Handling System

The basic data transferral unit within the data handling system is four bits (byte) parallel and byte serial. The average internal transfer rate is 800 kHz (200,000 bytes per second). Maximum data collection rates, however, are limited by program execution times and tape recorder speed. The present quoted limit, 45 kilobits per second, is a tape recorder limit.

There also exists, within the IOM, circuitry allowing direct communication between the experiment and the data handling system. It is thus possible via program instruction to cause a sensor or group of sensors to change their sampling scheme (or any commandable characteristic) at a known point in the program. It is also possible for sensors to set up conditions which cause the stored program to branch to a desired subroutine, handle the new data as required, and then return to the normal collection mode determined by the main program instructions.

(2) CPU: The CPU provides the executive functions for the data handling system, which include the executing of stored program instructions, formatting data, addressing the buffer and program memories, outputting data to telemetry or the tape recorder, and interrupt servicing.

Since the internal operations of the CPU have no direct impact on data acquisition and detector control, they will not be discussed further.

(3) Buffer memory: The buffer memory provides for temporary storage of certain data types to allow for data acquisition at times other than at requests to fill the telemetry format. Examples of such acquisitions are the occasional rapid collection of data at rates exceeding the telemetry rate, the collection of data asynchronous with the telemetry clock as discussed under "Program Memory," below and data called for by high-priority interrupt lines. The latter provision

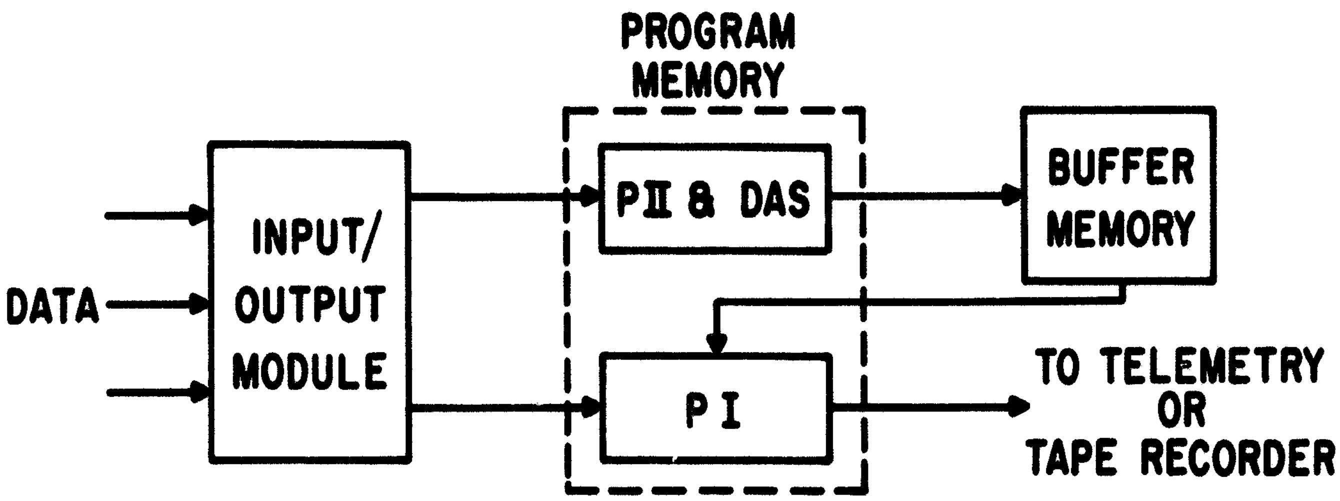

Figure 4–Data Flow Controlled by the PI, PII, and DAS Programs.

allows data acquisition for rarely occurring random events. In addition, the buffer memory provides index registers and program address registers.

The buffer memory contains 4,000 words of four bits each for a total of 16,000 bits. The design is modularized so that the size of the memory can be varied in 2,000-bit increments. The buffer memory is designed as a random access, coincident current, destructive readout device and reads and writes four bits parallel. The access time is 5μsec per byte (four bits).

(4) Program memory: The program memory contains instructions that, when executed by the CPU, result in data acquisition, temporary data storage, formatting, control, and other on-board data handling system operational functions. This memory contains core locations for a maximum of 256 instructions of 14 bits each, giving a total of 3,584 bits. Operationally, these instructions, of which there are only nine types, are similar to the statements used in a simplified computer assembly language. The set of instructions can be changed by ground command.

The memory is designed as a random access, word select, nondestructive-readout device in order to provide the most assurance that the program will remain intact through operation of the spacecraft.

Within the program memory there can reside up to three types of independent programs: program I (PI), program II (PII), and direct-access subroutines (DAS). The data flow controlled by these programs is shown schematically in Figure 4.

The primary mode of operation of the data handling system is established by the PI program, whose function is to output data to telemetry (or the tape recorder) in the basic telemetry format shown in Figure 5. This telemetry format contains a frame length of 256 bytes (4 bits/byte), 232 of which are filled with data by the PI program. The remaining 24 bytes are fixed in length and position and contain items such as parity, sync words, program instructions, etc. PI may obtain data directly from the IOM or buffer memory. PI operation is timed by the satellite clock in order to maintain a constant telemetered output bit rate.

The PII program is an optional sampling program stored in the program memory. This second program operates independent of telemetry format restrictions by using the buffer memory to store the data collected from where it is outputted to telemetry by the PI program (see Figure 4). The PII program is operated by one of two clocks, selectable by program instruction. One of the clocks may be nonsynchronous to the satellite clock. This last feature makes available some relatively new sampling techniques. Most notable of these is the ability to collect data completely asynchronous with the satellite clock. An example

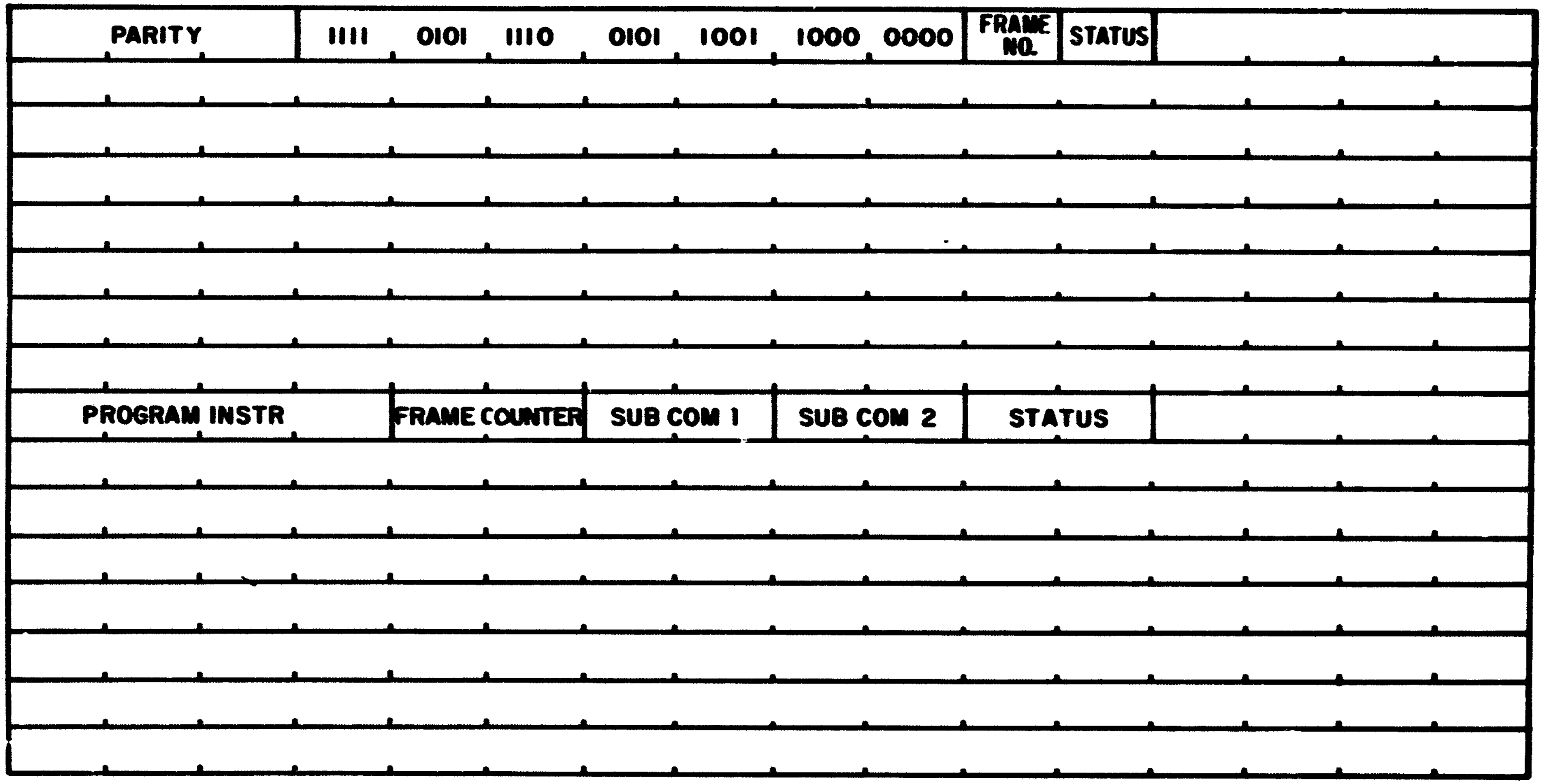

Figure 5—Basic S^3 Telemetry Format. Distance Between Tic Marks Represents One Byte (Four Bits). Information to Fill Undesignated Bytes Controlled by On-board Programs

of this mode is the collection of data in sync with the spacecraft roll rate. In this case, the PII program is operated by a data synchronous clock (DSC in Figure 3) which is constructed from the periodic sun pulses seen by the solar aspect detector. Also, several detectors can be sampled at a high time-resolution rate. With this method, it is possible to collect a burst of data, on the order of thousands of bits, at a rate considerably higher than the normal sampling rate. Such a burst of data would be loaded into the buffer memory and then read into telemetry over a much longer period of time than it took to collect the data. Quasi-simultaneous sampling also can be performed. It is possible to rapidly sample a number of signal input lines successively into the buffer memory, thus simulating the sampling of all the detectors at the same point in time.

The DAS are optional subroutines stored in the program memory which are entered directly upon the fulfillment of a test condition within the experiment. The DAS perform the desired operations and store the data in the buffer memory, from where it is outputted by PI (see Figure 4). An example of this mode is the recording of the time of randomly occurring events, such as the passage of stars through the field of view of a star-scanning device.

The total S^3 on-board data handling system (Figure 3) nominally will weigh about 7 lbs and draw about 4.5 watts.

(5) Additional on-board data handling features: The command system for in-flight program changes is a PCM system with a bit rate of 128 bps and a word length of 64 bits. This word length allows the reloading of any or all of the program memory instructions and allows up to 128 spacecraft commands. Synchronization bits and parity check bits are required to allow essentially error-free loading. The entire program memory can be reloaded in about 2-1/2 minutes. The command system will weigh less than 2.5 lbs and draw less than 1 watt.

The S^3 spacecraft will use a tape recorder for large capacity on-board storage. An endless-loop recorder design has been chosen for minimum weight and power. The recorder can hold up to 300 feet of tape, with a packing density of 3,000 bits per inch, giving a total storage capacity of 10.8×10^6 bits. The tape speed upper limit of 15 inches per second gives a maximum input and output bit rate of 45 kilobits per second. The ratio of record to playback speeds may be selected for each mission in the range between 32:1 and 1:32. In the event of recorder failure, the recorder can be bypassed and the data stream sent directly to the transmitter. The recorder will weigh approximately 6 pounds, and draw 2 watts in the record mode and 4 watts in playback.

The S^3 spacecraft will have a transmitter that will operate at two different power levels. Under normal operation, the high power mode will be turned on only

when data are being transmitted from the tape recorder. The low power mode will be used for real-time transmission when required. The transmitter will operate in the 136 to 138 MHz band. The antenna system consists of four dipole antennas spaced 90 degrees apart on the surface of the spacecraft cover. The elements form a canted turnstile and are fed from a coaxial hybrid diplexer in phase quadrature to produce a standard IEEE radiation pattern. Tracking will be accomplished with a range and range-rate system or with interferometer tracking, depending on the experimenter's requirement for orbital position accuracy.

(6) Summary: In summary, the on-board data handling system is primarily a processor for acquiring and formatting data; it provides for flexibility in data acquisition on a given mission and in accommodating the data processing on future unknown missions.

Ground Data Handling. The ground data reduction and processing system is an integral part of the Small Scientific Satellite concept. As such, the ground data system will be capable of automatically handling inflight format changes. To do this, the satellite telemetry message includes the words of the format memory so that the ground computers can reconstruct the satellite memory and appropriately unpack the data. Also, if any changes occur, the ground program will automatically flag this change for the experimenter. The ground system will also be capable of handling several satellites without overloading and will be capable of changing from one satellite to another with a minimum of effort.

A general block diagram for the ground data processing system is presented in Figure 6. In Figure 6 (a), a data tape from the station containing the raw telemetry data from the satellite enters the ground processing system, where conversion to a binary computer format is made. At this stage, time is either checked on the satellite data tape or added when necessary, and data quality is established and written on the binary tape. In Figure 6(b), the binary data tape enters a series of data reduction and handling programs which reconstruct the telemetry format, unpack the data into defined words, and construct whatever dictionary or encyclopedia formats are required. The program will also insert satellite orbit and calculate any parameters needed for data analysis. The program will then produce summary listings and [illegible]ry plots of selected detectors so that the experimenter can rapidly utilize the in-flight reprogrammable capability of the S^3 system as well as identify periods in time when interesting events occurred. A final data tape will be produced which will contain all of the data from the satellite, orbit data, coordinate data, and all parameters the experimenter requires for analysis.

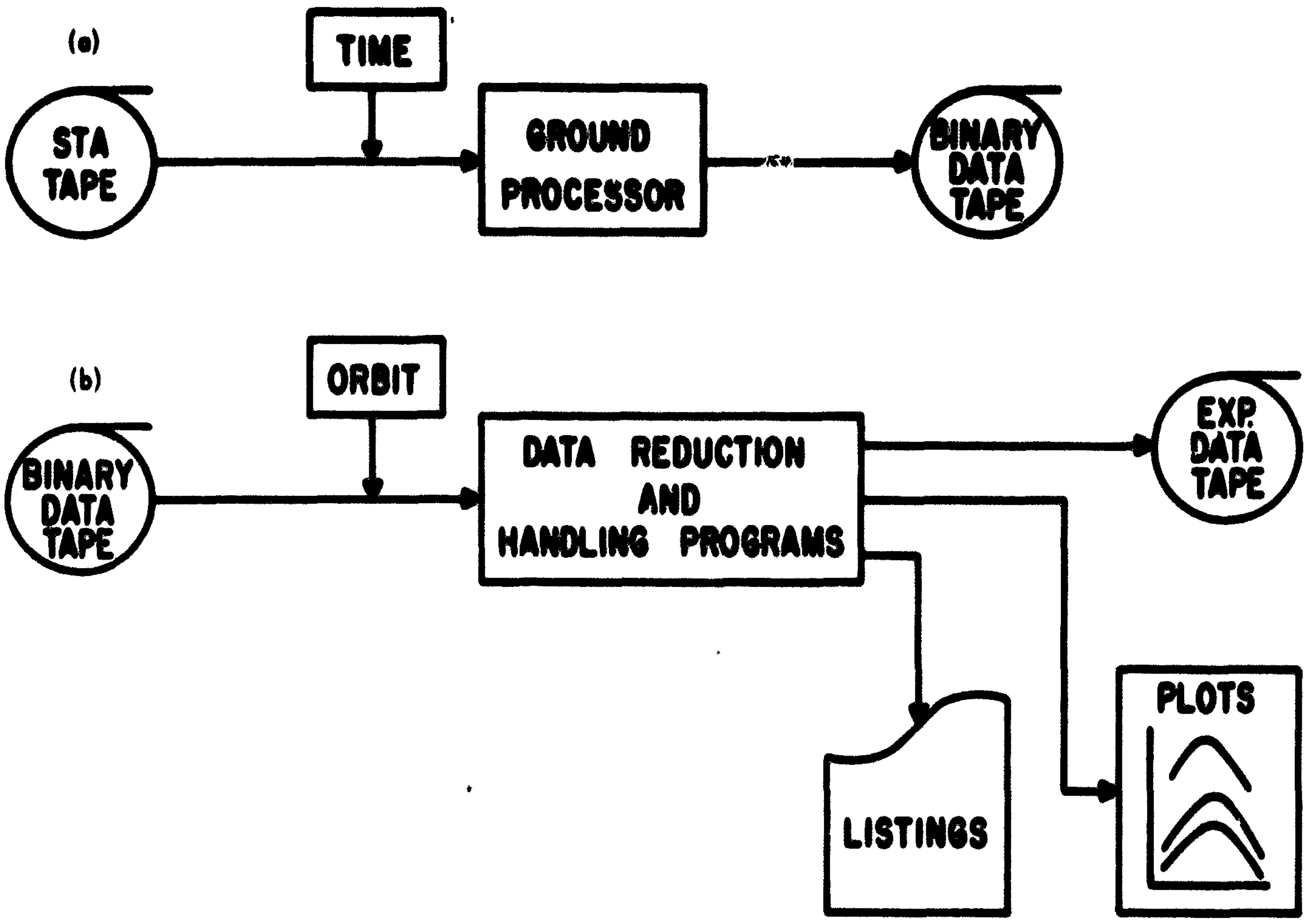

Figure 6–Basic S^3 Ground Data System

GROUND SUPPORT EQUIPMENT (SPACECRAFT CHECKOUT)

The S^3 project will use a PCM data processing, performance analysis system (PAS) in order to evaluate the spacecraft system performance during spacecraft integration, environmental testing, and prelaunch checkout. In addition, real-time quick-look processed telemetry data during the launch and early orbit phases may be necessary for operational decision-making before the data become available from the normal data processing production lines.

The PAS, permanently located in the Electronics Systems Branch laboratory at GSFC, will be used for the early phases of the S^3 program. (This laboratory system is configured about a SDS-930 computer.) Beginning with the prelaunch operation for the first S^3 launch, however, a mobile PAS (capable of operating at any remote launch site) will become the primary S^3 GSE.

The mobile PAS is centered around the SDS Sigma 5, a third-generation integrated circuit general-purpose digital computer. A PCM front end is attached

to the computer to obtain synchronization and signal conditioning. The complete system is mounted in a set of two shelters (vans) that are land, sea, and air transportable and capable of operating at remote sites with varying climatic environments.

S^3-A, THE FIRST S^3

A brief description of the first satellite in the S^3 program, S^3-A, will be given as a nominal example of the capability of the program. The launch of S^3-A is scheduled for 1970.

The primary objectives of the S^3-A mission are:

(1) to study the characteristics and origin of the earth's ring current and development of main-phase magnetic storms;

(2) to study the relation between magnetic storms, aurora, and the acceleration of particles within the inner magnetosphere;

(3) to determine the major wave-particle interaction mechanisms responsible for particle transport and loss in the inner magnetosphere;

(4) to determine the relative importance of various diffusion mechanisms in populating the radiation zones.

Figure 7 shows the configuration for S^3-A as it fits into the Scout fairing, and Figure 8 shows an artist's conception of S^3-A in orbit with experiment booms deployed.

Table 4 lists particulars of S^3-A chosen by the experimenters in order to meet mission objectives. The first item in Table 4 is of notable interest, since a $\leq 10°$ inclination requires that S^3-A be launched from the San Marco launch facility, which is a "Texas Tower" type platform operated by the Italian government off the coast of Kenya, Africa, at a latitude of 3°S.

The spin axis is being placed in the plane of the orbit. Because of the dipole character of the earth's field, particle angular distributions with respect to the local magnetic field direction may be obtained by placing the detector look angles perpendicular to the spin axis and dividing the spin period into many sampling periods. The spin axis will also be confined to remain within 20° to 70° of the satellite-sun line in order to avoid an unfavorable solar input to the detectors. The lower structure solar cells, shown extended in Figure 8, take advantage of the required spin-axis orientation to pick up additional power. S^3-A beginning-of-life power will be 31 watts.

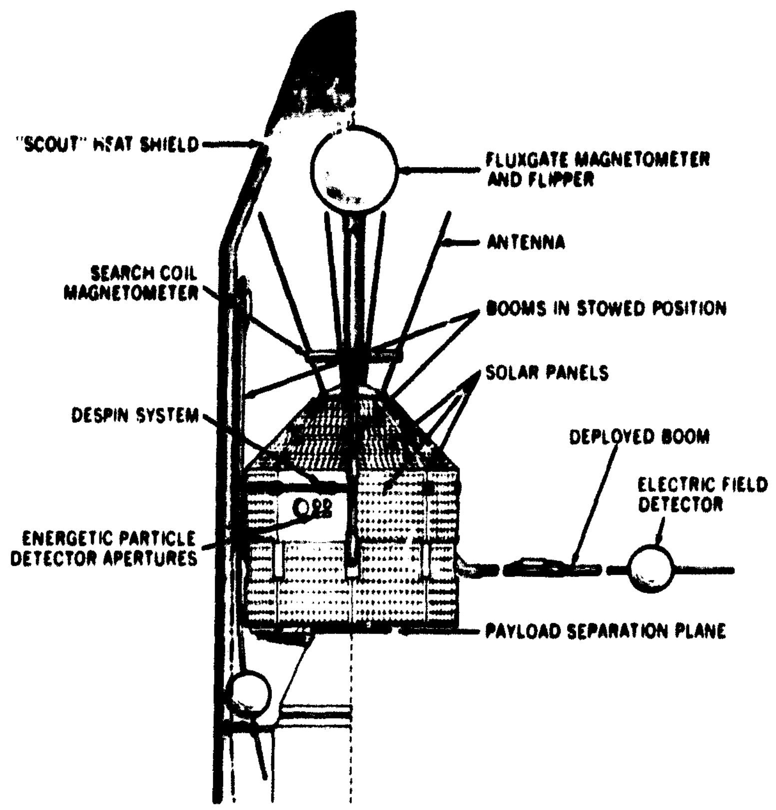

Figure 7—S^3-A in Scout Fairing

Table 4
S^3-A Characteristics

- Orbital Inclination $\leq 10°$; Apogee 5 Earth Radii
- Spin Axis in Plane of Orbit
- Spin Rate 4 RPM
- Spin Rate and Orientation Control (ASCS)
- Data Collection Synchronized to Spin Rate
- Aspect Determination to 0.1° (SCADS)
- Tape Recorder
- Bit Rate into Tape Recorder 440 Bits per Second

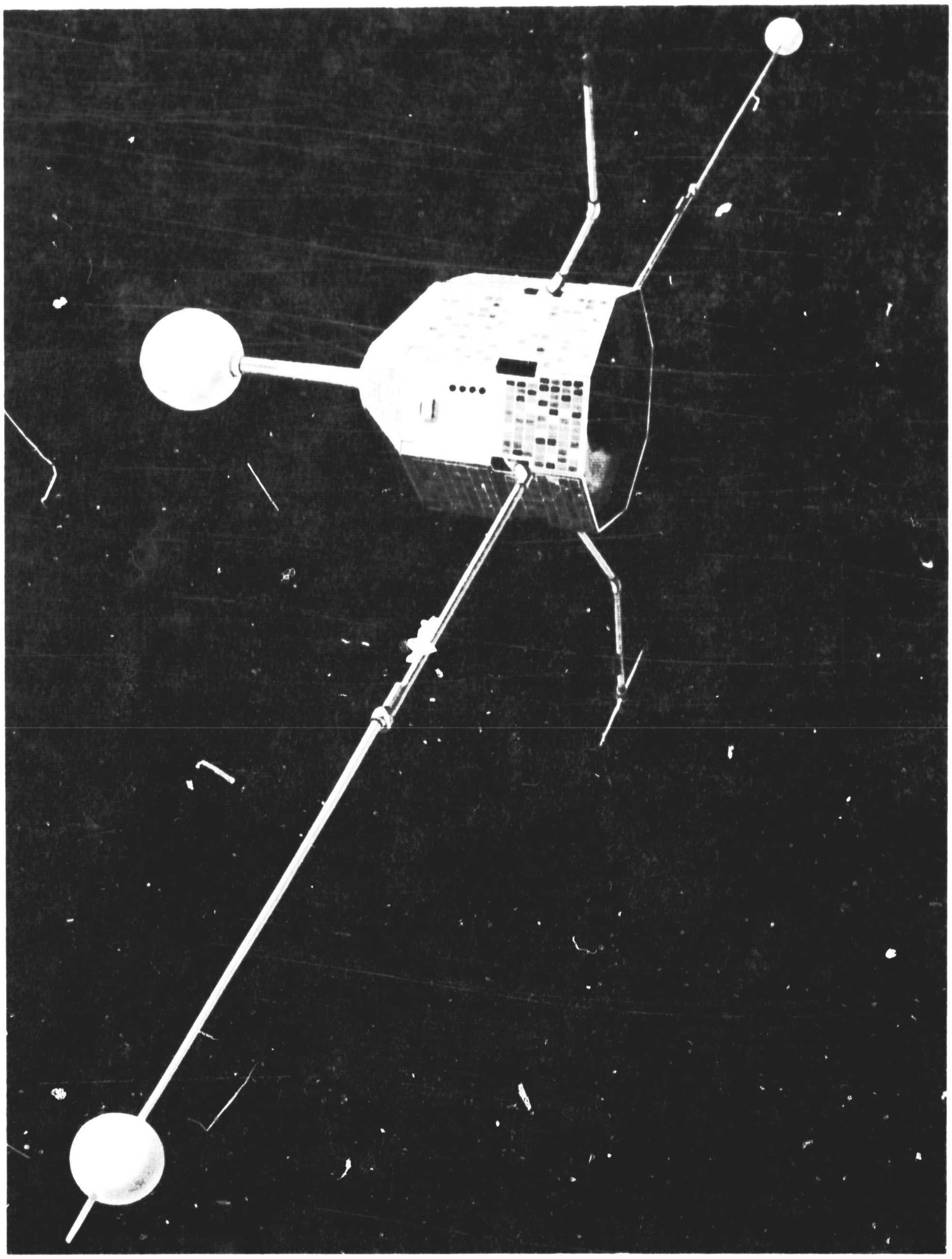

Figure 8—Artist's Conception of S^3-A in Flight with Booms Deployed

At the bit rate of 440 bps, the tape recorder capacity of $10.8\ (10)^6$ bits gives a record time of 6.8 hours. The orbital period for S^3-A is slightly over 7 hours, so essentially full orbit coverage is achieved. The tape recorder will be read out through the high power mode of the transmitter at a rate of 14,080 bps.

Table 5 lists the experimental measurements to be made on S^3-A. The detector complement consists of a variety of particle detectors and electric and magnetic field sensors.

All spacecraft options listed in Table 3 are being flown on S^3-A. Thus the total S^3-A payload weight breaks down as:

Basic spacecraft	–	62.4 pounds
Optional subsystems	–	14.6 pounds
Experiments	–	30.4 pounds
Total	–	107.4 pounds

Table 5
S^3-A Detectors

TYPE	MEASUREMENTS	SENSITIVITY	WEIGHT	POWER
CHANNELTRONS	ELECTRONS AND PROTONS 500 ev TO 25 kev IN 8 OR 16 STEPS	10^5 TO 10^{10} PARTICLES/ cm^2-sec-ster	3.7	1.3
SPIN-ALIGNED DETECTORS	ELECTRONS 2 kev AND 20 kev	10^5 TO 10^8 PARTICLES/ cm^2-sec-ster	0 6	–
SCINTILLATOR	PROTRONS 20 kev TO 35 kev 35 kev TO 70 kev 70 kev TO 120 kev 120 kev TO 200 kev	10^3 TO 10^9 PARTICLES/ cm^2-sec-ster	4 4	1.0
SOLID STATE DETECTORS	ELECTRONS 35 kev TO 70 kev 70 kev TO 140 kev 140 kev TO 250 kev 250 kev TO 400 kev PROTRONS > 300 kev, > 500 kev > 750 kev, > 1000 kev	10^4 TO 10^9 PARTICLES/ cm^2-sec-ster	3.0	0 8
MAGNETIC FIELDS			12 6 INC. BOOMS	1 7
FLUX GATE	VECTOR FIELD, dc TO 10 Hz	< 5 gammas		
SEARCH COIL	FLUCTUATIONS 1 TO 3000 Hz	4 TO 0.001 gamma		
ELECTRIC FIELDS			6.1 INC. BOOMS	1.2
DC	TWO COMPONENT dc FLUCTUATIONS 0.3 TO 30 Hz	0.1 milli volt/meter		
AC	20 Hz TO 200 kHz		(TOTAL WT 30.4)	(TOTAL PWR 6.0)

Of the 107.4 pound total payload, 45 pounds (30.4 experiments and 14.6 optional subsystems) or ~42% are at the option of the experimenters. The sensors are now briefly described below.

Magnetic Field

The vector magnetic field will be measured from dc to ~10 Hz with a three-axis fluxgate magnetometer to a sensitivity of less than 5γ ($1\gamma = 10^{-5}$ gauss). The field magnitude in the region of interest varies from ~100γ to ~$4{,}000\gamma$. The individual sensors, along with a commandable flipper mechanism to check zero levels, are housed in the sphere at the end of the single boom extending along the satellite spin axis as shown in Figure 8. The short booms in Figure 8 hold two orthogonal search coil magnetometers measuring ac magnetic fields from 1 to 3,000 Hz. The search coil outputs will be routed to sets of filters each nominally sampled at a once-per-second rate. In each set, three filters have fixed bands and three have swept bands.

Electric Field

The electric field antenna consists of two 5-1/2 inch diameter metal spheres mounted on the ends of the long booms shown in Figure 8. The tip-to-tip distance is 16 feet (4.9 meters).

The dc electric field measurement is obtained by monitoring the potentials of the two spheres with respect to the spacecraft, and subtracting these potentials differentially to remove the effects of the spacecraft. The resulting potential difference divided by the distance between the spheres is a measure of the component of electric field and $\vec{V}\times\vec{B}$ field (due to the satellite velocity $\vec{V}$ in the geomagnetic field $\vec{B}$) along the axis of the antennas. Geoelectric fields at apogee as small as ~0.1 volt/meter should be detected. The rotation of the spacecraft allows a two-component measurement to be made. A calibration plate on the spacecraft will be used to change the spacecraft potential, thus checking on sheath overlap errors. In addition to the dc measurement, four rms spectrometer channels will sample low frequency variations between 0.3 and 30 Hz.

The ac portion of the electric field measurement apparatus will consist of a series of narrow-band filters covering the frequency range 20 Hz to 200 kHz, which includes magnetospheric plasma frequencies at which electrostatic wave phenomena may be expected in this region of the magnetosphere.

The ac signal from the spheres drives two high-input impedance unity gain preamplifiers also mounted on the booms. A differential amplifier is used to

obtain a signal proportional to the potential difference between the spheres. After amplification, the differential amplifier signal goes to a set of 16 narrow-band filters covering the measured frequency range. The filtered signals are sequentially selected by a switch whose position is commutated by logic in the spacecraft data handling system. The selected filter signal is amplified by a log compression amplifier and detected to provide an analog voltage proportional to the logarithm of the noise intensity in that channel. This analog voltage is then sampled by the data handling system and telemetered in digital form.

As a test to insure that the ac measurement is indeed obtained from fields in the magnetosphere, rather than from potential fluctuations due to variations in density or temperature of the surrounding plasma, another antenna system will be flown mounted on one of the search coil magnetometer booms (as shown in Figure 8), and parallel to the primary electric antenna system. This antenna will consist of two spherical wire mesh grids 2-1/2 inches in diameter with a center-to-center separation of about 2 feet.

Wide-Band Telemetry

As a supplement to the ac outputs of both the electric field detector and search coil magnetometers, which will normally be sampled with series of band pass filters, the transmitter, via ground command, will be used on a limited basis for wide-band data transmission. The output of a 300 Hz to 10 kHz broad-band filter from the ac electric field detector will be mixed with two outputs of the search coil magnetometers, which will have been placed on subcarriers with frequencies above 10 kHz. This wide-band transmission will assist in the interpretation of the data from the band pass filters.

Channel Electron Multipliers

The channel electron multipliers,[6] in conjunction with cylindrical curved-plate electrostatic analyzers, will provide the basic particle detector system in the energy range between 500 ev and 25 kev. A diagram of the channel multiplier and a photograph of the multiplier and analyzer plates in flight configuration are shown in Figure 9. To achieve the energy range, a stepped voltage will be applied to the analyzer plates.

The analyzer resolving power is capable of achieving a 30-percent particle transmission at energy levels of 0.85 E_0 and 1.25 E_0, where E_0 is the energy most sensitive to the analyzer.

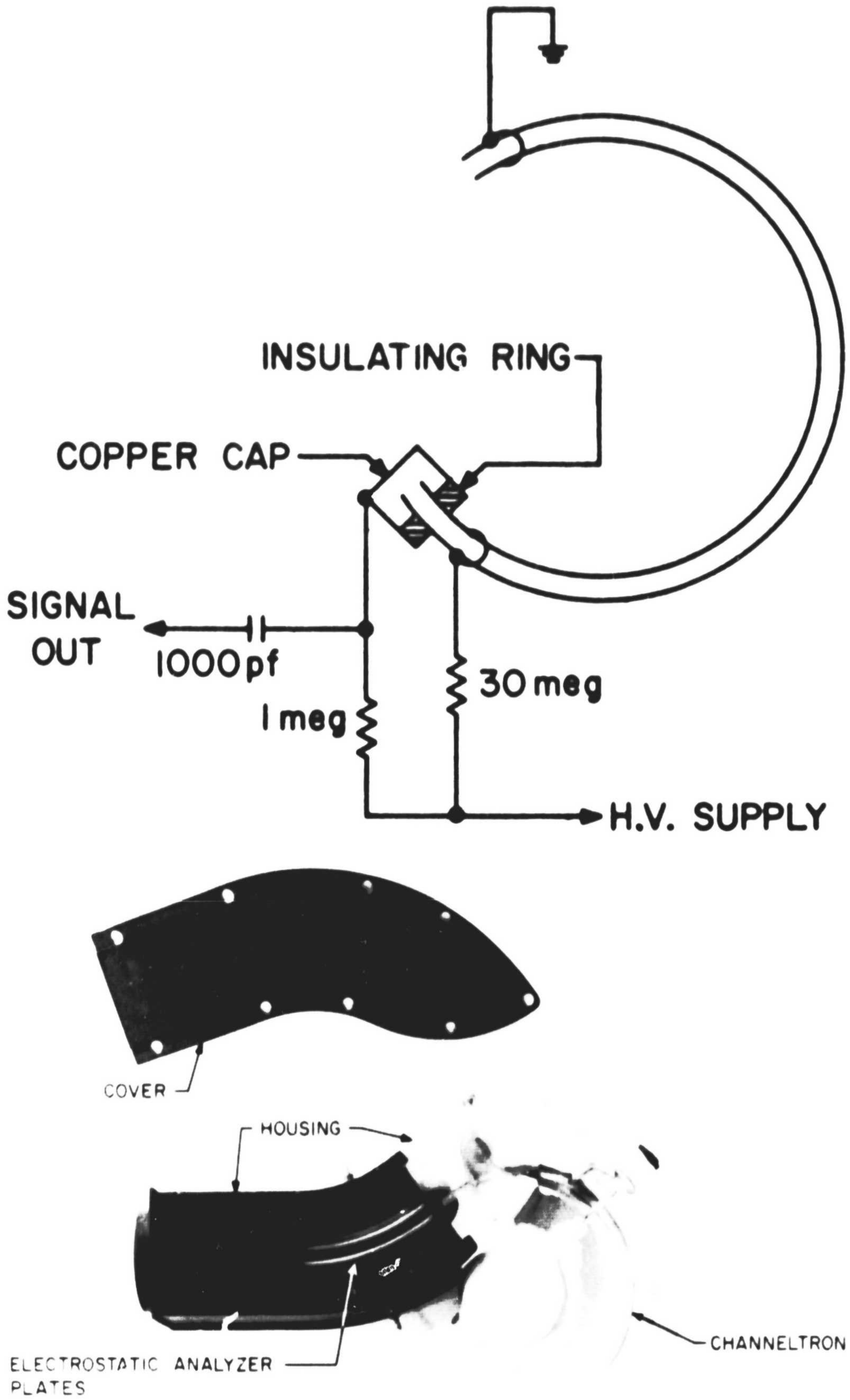

Figure 9—Basic Components of Channel Multiplier and the Flight Configuration of the Channel Multiplier and Electrostatic Analyzer

The channel multiplier particle detectors will be operated in the gain-saturated mode. They function reliably at counting rates approaching 100,000 Hz when coupled with gain/low threshold amplifiers/discriminators. Lifetimes will exceed 1 year at counting rates of 2,000 Hz.

The significant counting-rate dynamic range of the channel multiplier is assumed to be $\approx 10^2$ to 10^5 Hz. Variations in the geometric factors achievable by the basic detector system will allow the study of particle fluxes from $\approx 10^5$ to $\approx 10^{10}$ particles/cm^2 sec sterad of energies within the analyzer pass band. Since a single detector module has a dynamic range of only three orders of magnitude, as established by the channel multiplier, dual detector systems will be used for the 5-decade variation expected in particle flux.

A small sunshade in front of the analyzer entrances will prevent any response to solar ultraviolet or X-rays. A plasma trap to be included will consist of two biased grid structures that prevent any charged particles of energy less than 6 ev from entering the analyzer.

Zinc Sulfide Thin-film Scintillator

A thin-film ZnS (Ag) scintillation detector will be used to measure proton intensities in the energy range from 20 kev to 150 kev in four steps. The ZnS (Ag) scintillator is a transparent polycrystalline film approximately 2 mg/cm ^{2} thick. The experimental ΔE vs E curves for a 15,000 Å thick ZnS crystal with a 400 Å thick Al covering are shown in Figure 10 for the cases of

(1) No foil in front of the scintillator, and

(2) A 30-μinch Ni foil in front of the scintillator (F. Soraas, private communication).

Through the use of differential pulse-height analysis, protons in the following four energy ranges will be selected: 20 to 35 kev, 35 to 70 kev, 70 to 120 kev, and 120 to 200 kev (including background). Thin nickel foils will be rotated into the detector aperture to modify the proton spectrum striking the scintillator, and to prevent protons below the lower energy threshold from causing pulse pileup. A small broom magnet in the aperture will sweep out low-energy electrons, also to eliminate pulse pileup.

The telescope factors will range from 10^{-2} to 10^{-5} cm^2-sterad. The basic detector has a dynamic range of 1,000 to 1 (20,000 to 20 Hz), which will be significantly increased by using two sets of apertures. Logic circuits built into the detectors will automatically select the appropriate aperture. Integral fluxes of 10^3 to 10^9 protons per cm^2 sec sterad will be measured.

Solid State Detectors

Figure 11 shows the housing assembly for the solid state detectors being used to measure electron intensities in the ranges 35 to 70 kev, 70 to 140 kev, 140 to 250 kev, and 250 to 400 kev. A 1,000-gauss magnet will be used to define the above energy bands and four 300μ, 0.25 cm^2 surface barrier detectors will monitor the intensities. The container for the magnet and detectors is a special heat-treated, high-permeability 80 Ni, 20% Fe material which provides a hard magnetic shield which satisfies spacecraft magnetic specification.

The electronics consists of charge-sensitive preamps, amplifiers, and discriminators which then interface the random pulse channel of the IOM. The charge-sensitive preamps, in flight configuration, have a full-width-half-maximum (FWHM) noise of about 2 kev with a zero picofarad (pf) input capacity. The detector-preamp system used gives a nominal FWHM of about 10 to 11 kev. These characteristics are obtained at room temperature and with two differentiations and one integration of 0.8 μ sec each.

A thin 15μ surface barrier detector will sample protons with energies greater than 300 kev incident upon it. This detector will be mounted in the scintillator package behind the same wheel which rotates the nickel foils into the scintillator aperture, and will have its own set of foils to raise the low-energy threshold for proton detection. Thus actually four integral energy measurements will be made, of energies greater than 300, 500, 750 and 1000 kev.

Spin-aligned Detectors

In addition to the above detectors, which, through the utilization of the spin of the satellite, measure the pitch-angle distributions of the particles, two detectors will be positioned to look parallel to the spin axis. They will obtain variations in intensity of the near locally mirroring particles, because the spin axis will be oriented nearly perpendicular to the magnetic field lines. These detectors, both of the channel electron multiplier type, will measure electrons of about 2 and 20 kev with high time resolution.

SUMMARY

We have described the Small Scientific Satellite (S^3) program, and have shown how the program can provide experimenters with a true scientific "bench" in space. A single-mission concept allows a group of researchers the utilization of this entire bench for the solution of specific physical problems of interest. All parameters affecting the mission (orbit, orientation, etc.) are under the control

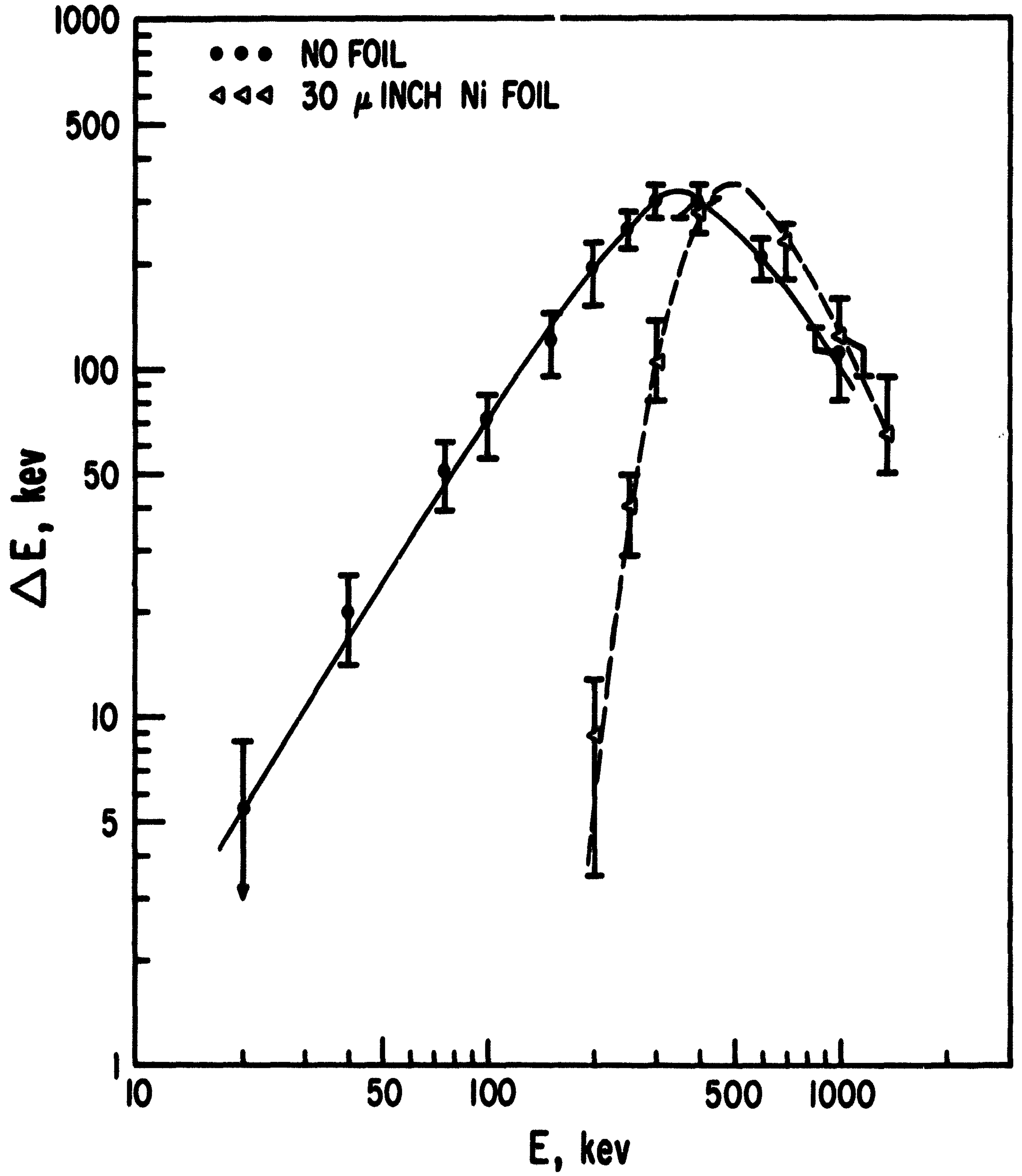

Figure 10–ΔE vs E Curves for ZnS Scintillator

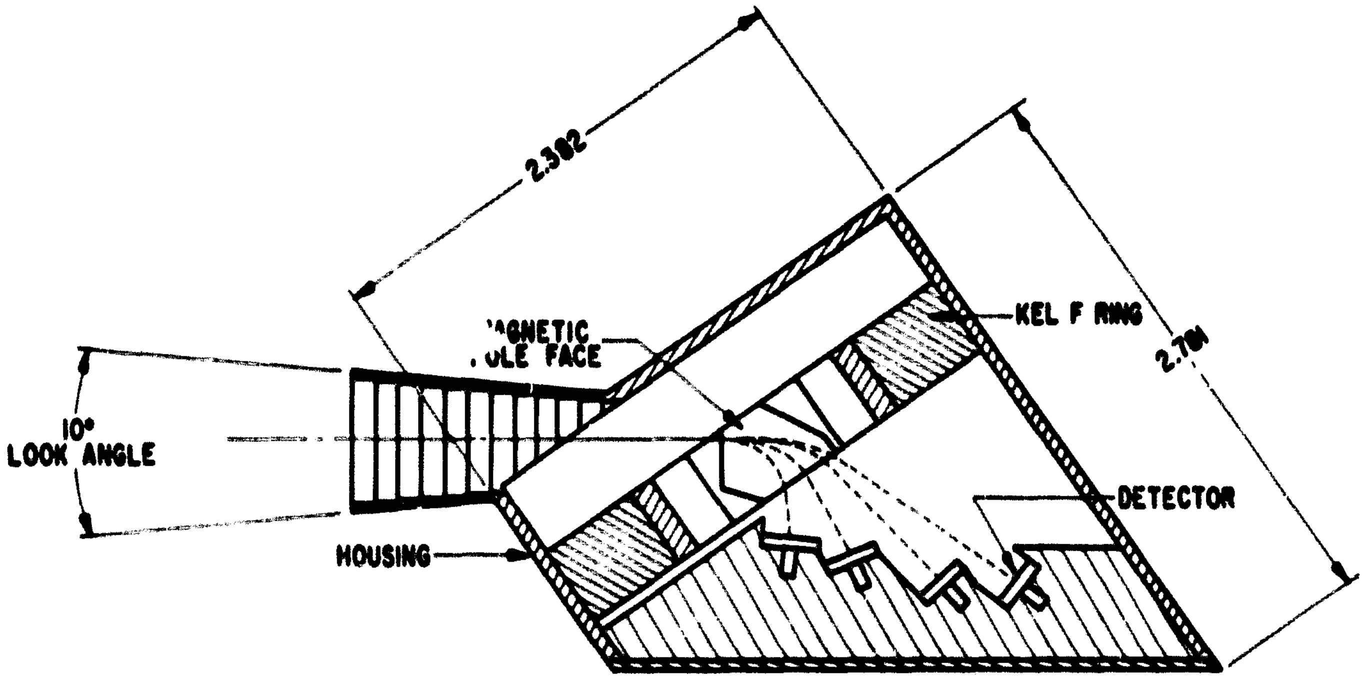

Figure 11–Flight Housing for Magnetic Analyzer and Solid State Detectors. Nominal Electron Trajectories Shown. Energy Range Covered is 30 kev to 400 kev

of the experimenter. Most important is the feature that data collection from the experiment is also under the complete control of the experimenter through the use of on-board stored programs which govern inflight data sampling and handling. These programs may be changed at any time through ground commands to allow the experimenter full use of his bench.

It is the data acquired with such instrumentation systems, now and well into the future, that will le l to a scientific understanding of the processes which shape the earth's environment and which govern its interaction with the solar system.

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It is not possible to list all the persons who are making S^3 a reality through their professional and enthusiastic services. It is with great personal and professional pride that we can associate ourselves with this project.

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